Evaluating Managed Aquifer Recharge and Aquifer Storage and Recovery in Kabul, Afghanistan Using Regional and Site-Specific Groundwater Models

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INTRODUCTION

The Kabul Managed Aquifer Recharge Project (KMRAP) is focused on the hydrogeological conditions in Kabul with particular attention to pilot schemes for Managed Aquifer Recharge (MAR). Despite the apparent simplicity of MAR approaches and their large implementation worldwide, the complexity of site-specific hydrogeological conditions, and processes occurring at various scales require a thorough understanding of the hydrologic system’s response to proposed measures. Characterizing a hydrologic system, including any heterogeneity and anisotropy, is most effective when the investigation includes, but is not limited to, exploratory drilling and sampling programs, and additional pumping tests.

Numerical modelling used in conjunction with a conceptual model of the hydrogeologic system and the results of field investigations can allow for thorough understanding of the hydrologic system’s response to proposed measures. Characterizing a hydrologic system, including any heterogeneity and anisotropy, is most effective when the investigation includes, but is not limited to, exploratory drilling and sampling programs, and additional pumping tests.

Regional Model

Initial numerical modelling efforts for KMRAP began with a 3D regional steady-state model for the basin, built in FEFLOW utilizing the knowledge and findings to date to prepare a comprehensive conceptual model for Kabul’s groundwater system.

Main Key Objectives

1. To understand the groundwater regime
2. To prepare a water budget and quantify recharge
3. To provide a tool for Groundwater Management

The project area is located in Afghanistan in the province of Kabul, covering all the Kabul city (34.5347° N, 69.1304° E). The area covered is approximately 400 km², as shown in Figure 1.

Figure 1 - Model Location and Boundary Conditions (BCs); Kabul is divided by two main sub-basins; Kabul West and Kabul East

The identified geological units (i.e. model layers) consist of a shallow Quaternary aquifer overlying the Neogene aquifer. The Neogene aquifer is separated into N1 and N2 as shown in Figure 2. Kabul shallow main aquifer (indicated in blue in Table/Figure 2) represents a total volume of 8 billion m³. If only considering an average porosity of 10% to 12%, the available water storage capacity would be already equal to 1 billion m³. Similarly, the confined Neogene aquifer with a total volume of 49 billion m³ could represent a significant water storage capacity. Limited studies are available. But from a lithological point of view, the Neogene aquifer is very similar to the Shallow Quaternary, only the grade of compaction and the water saturation differ. A water storage capacity of 3.5 to 4.9 billion m³ could be conceivable. These values highlight the interesting potential that such alluvial aquifers may represent in terms of water availability and management, using MAR or other ASR techniques.

Preliminary Results

Water budget (Figure 3) in terms of total volume indicates that around 32,000 m³ are flowing daily in and out the model domain, with an imbalance sum equal to 0. Under natural conditions, the several aquifers are in a state of dynamic equilibrium: groundwater recharge equals to discharge to streams and outlet boundary conditions. The rivers participate in the water budget (Paghman, Kabul, and Logar rivers). Usually rivers recharge the aquifer in Western parts of the basins and drain it while recharging basins in Eastern basin. Project, Afghanistan area for the Western basin and Tanghi Gharu for the Eastern basin (Figure 1). Tanghi Gharu gorges represents the principal Kabul aquifers outlet.

Figure 2 – Regional model implementation, vertical extension, hydraulic parameters and groundwater flow

The numerical model is constituted of 4 numerical layers, with a total of 68,432 triangle nodes, including mesh refinement along the rivers and MAR sites. The first layer is a phreatic type that covers an unconfined aquifer (i.e. Quaternary shallow aquifer).

Figure 3 – Water balance in m³/day

Site-Specific Local Models - MAR SITE 3

MAR Site 3 is located in Dugh Abad area and is on private land (see Figures 1 and 4). The project in site MAR 3 will be a combination of a spreading basin and injection wells (gray wells). The numerical model including the spreading basin has been prepared and sensitivity tests have been run.

Main Key Objectives

1. To estimate the feasibility of this MAR method
2. To compare different operational schemes (spreading basin alone or coupled with injection wells)
3. To provide future predictions and operational strategies

The spreading basin would be 300m by 100m and 2m deep. The base of the spreading basin would be approximately 40m by 220m. The base would comprise 300mm thickness of siliceous gravel to enhance natural infiltration. Figure 4 presents the site details and features with; 1- the Kabul river (water source), 2- the irrigation canal for the water inflow into the sedimentation basin, 3- the sedimentation basin for sediment control and 4- the infiltration basin or spreading basin.

Figure 4 - Model implementation and vertical extension of the regional model

Boundary Conditions are extracted from the regional model, namely imposed Head BC’s imposed West and East limits. Transfer boundary conditions (Cauchy) are assigned in the spreading basin as special boundary conditions, with a value of pressure head (calculated at each time step and equal to the basin water level) and a constant Tr coefficient corresponding to the sand layer.

Water mass balance in basin using fmlake FEFLOW plugin – in fmlake plug-in allows integrating spreading basins within a FEFLOW model. A water mass balance calculation within the basin is possible as illustrated in Figure 6. Maximum extent of the infiltration area is defined with a nodal distribution at the bottom of the basin. Water mass balance are calculated by linking the water level and the water volume in the basin.

Figure 5 – MAR Site 3 specific site model boundary conditions

The Plots in Figure 7 present the results of the simulation after one year of basin filling with the green line indicating the inflows in m³/day into the spreading basin and the blue line for the recharge component. Three sensitivity cases are presented:

1. Natural recharge only from the spreading basin (Plot a)
2. Recharge from spreading basin and additional well recharge, 20 cm (Plot b)
3. Recharge from spreading basin and well field, 20 cm (Plot c)

1. 10,000 to 15,000 m³/day of direct infiltration (natural recharge) are achieved in the spreading basin without additional ground well once surface soils reached saturation (Plot a).
2. There is a direct correlation between water input into the basin and recharge from the well, it shows the sensitivity of the model when introducing one single injection well (in blue) (Plot b).
3. The well field assists positively the basin infiltration, additional 25 to 20% of water can be infiltrated (Plot c).

Presented sensitivity tests shows that important quantity of water can be infiltrated through a spreading basin that can be properly simulated and different infiltration schemes tested. The approach coupling surface water with underground water to simulate these types of MAR spreading basin method shows promising perspectives.

Figure 6 – Process Loop for P4-Lake BC, it allows integrating lakes within FEFLOW model, and calculate a water mass balance

Figure 7 – Sensitivity test results, a) basin alone, b) basin + one well and c) basin + well field

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MAR to solve the global water crisis